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Frequency Control for Island Operation of Bornholm Power System

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Abstract

This paper presents a coordinated control strategy of a battery energy storage system (BESS) and distributed generation (DG) units for the island operation of the Danish island of Bornholm. The Bornholm power system is able to transit from the grid connected operation with the Nordic power system to the isolated island operation. In order to ensure the secure island operation, the coordinated control of the BESS and the DG has been proposed to stabilize the frequency of the system after the transition to the island operation. In the proposed coordinate control scheme, the BESS is used to provide the primary frequency control and the DG units are used to provide the secondary frequency control. As such, the proposed control scheme can strike a balance of the frequency control speed and the energy used from the BESS for the frequency control support. The real-time model of the Bornholm power system was used to carry out case studies using real time digital simulator (RTDS) to illustrate the performance of the coordinated control strategy. Case study results show that the proposed control strategy can efficiently help stabilize the frequency under different conditions.

Keywords: Battery energy storage system (BESS), distributed generation (DG), island operation, load frequency control (LFC), real-time digital simulator (RTDS)

1. Introduction

Denmark has a very pro-active energy policy. As it can be seen in the future energy outlook and policy of Denmark, more renewable energy integration is planned in the near future. The Danish parliament has entered a new energy agreement and set a target of 50% penetration of wind power in 2020, 100% renewable energy penetration in the electricity and heating sectors in 2035, and 100% independent of fossil fuel in 2050 [1]. In relation to the planning and operation of the future energy system and smart grid technology development, the Bornholm Island is of great interest due to the characteristics of the

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Bornholm power system. The Bornholm power system has a high share of electricity supplied by renewable energy sources (RES) and can represent a future power system to a great extent in the island operation mode. The power generation on Bornholm consists of 1 steam unit, 1 combined heat and power (CHP) unit, two biomass generation units, 14 diesel units, and a large share of wind power generation supplying 30% of the total electricity consumption with an additional 20MW estimated to be installed in the near future. The future scenario of wind power installation will certainly create serious challenges to the power system operation and control. Additional power balancing is required for dealing with the intermittent characteristics of the wind power.

The Bornholm power system is connected through a long submarine cable to the Swedish power system. The sea cable can be disconnected to test a restricted area with a very high share of renewables. During these periods, frequency control of the system becomes fairly difficult. Several projects in Denmark have been carried out by Energinet.dk, the transmission system operator (TSO) [2-4]. Since the wind power generation is intermittent, they cannot guarantee the constant power supply required by loads. Furthermore, the DG units with relatively slow response have insufficient dynamic performance in terms of load tracking [5]. To deal with the frequency control challenges, the introduction of an energy storage system (ESS) is considered to be an effective solution. The Battery energy storage system (BESS) is the most efficient and compatible technologies because of its fast response and relatively large capacity. It is used to improve the power system operation and control with large renewable energy penetration. Quite man studies have been reported on the use of BESS [6–10].

This paper is to develop a coordinated control strategy of a battery energy storage system (BESS) and distributed generation (DG) units for the island operation of the Danish island of Bornholm. In the proposed coordinate control scheme, the BESS is used to provide the primary frequency control and the DG units are used to provide the secondary frequency control. As such, the proposed control scheme can strike a balance of the frequency control speed and the energy used from the BESS for the frequency control support.

The paper is organized as follows. The control strategy of BESS and DGs is presented in Section II. The Bornholm power system and BESS model are described in Section III. The case study results are presented in Section IV and a conclusion is drawn in Section V.

2. Control Strategy

The main concept of the control strategy is the coordination between the BESS and several distributed generation units, as shown in Fig. 1.

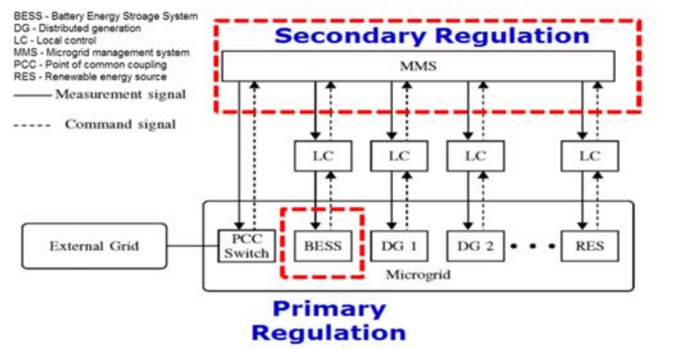


Fig. 1. hierarchical control structure

With the above control strategy, the following objectives can be achieved.

A. BESS Control

1) Grid-connected operation

The objective of BESS is maintaining the grid frequency and voltage within the permissible limits. In this mode, the task is mainly carried out by the external grid. Therefore, the BESS is not active.

2) Islanded operation

The power generated by RESs varies faster than traditional power generation. If there is no BESS, the power balance between the generated power and the existing loads does not always match due to the renewable energy fluctuations. As a result, the frequency and the voltage of the grid will fluctuate. This must be properly solved or it can lead to grid instability. Once the island situation is detected, the BESS is activated. Clearly, the BESS can provide fast response by proper power balancing as other DGs or thermal units have a relatively slow response time. Thus, the frequency of the grid can be effectively regulated. However, due to its capacity limitation, the BESS should be coordinated with other DGs or thermal units to share the load following burden. In the proposed coordinated control strategy as shown in Fig. 2, the microgrid management system (MMS) detects the change in the power output of the BESS and assigns the difference to the thermal units. This secondary frequency regulation control can reduce the consumption of the stored energy of BESS without degrading the control performance.

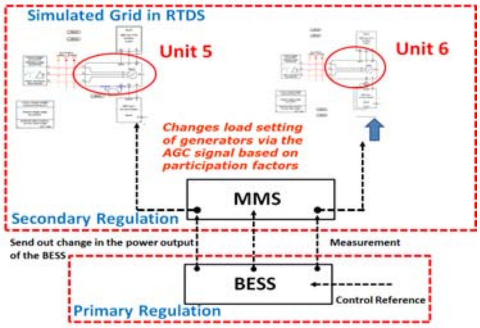


Fig. 2. Coordinated control strategy of BESS and MMS

In this mode, the quality of the frequency and voltage in the isolated grid are the key issues of concern and these mainly depend on the control performance of the BESS. This control strategy consists of a primary control action of the BESS and a secondary control action of the management system. The secondary load frequency control can be built in a number of ways, either locally or in a centralized and automatic way. The secondary load frequency control is performed as shown in Fig. 3. The centralized MMS control structure used in this work is based on the author's previous research [11-12].

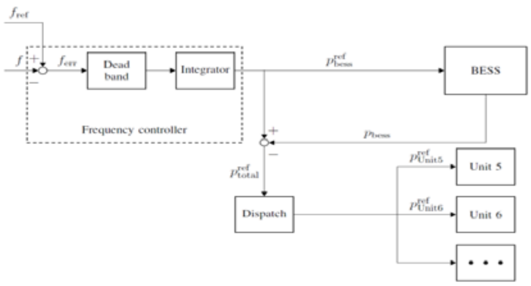


Fig. 3. Secondary load frequency control of the MMS

The power generation of the two thermal units are calculated as follows, Generation Unit 5:

$$P_{G5} = (\mathrm{P}_{SYS} - \mathrm{P}_{base,G6}) * \mathrm{pf}_{G5} \tag{1}$$

Generation Unit 6:

$$P_{G6} = (\mathrm{P}_{SYS} - \mathrm{P}_{base,G6}) * \mathrm{pf}_{G6} + P_{base,G6} \tag{2}$$

where, P_{SYS} and $\mathrm{P}_{base,G6}$ are the total system power and the base load of the unit 6, respectively, pf_{G5} and pf_{G6} are the participation factors respectively.

The load reference of each thermal unit must then be set in order to reach nominal frequency:

$$L_{ref,G5} = \frac{(\mathrm{P}_{SYS} - \mathrm{P}_{base,G6}) * \mathrm{pf}_{G5}}{S_{rated,G5}} \tag{3}$$

$$L_{ref,G6} = \frac{(\mathrm{P}_{SYS} - \mathrm{P}_{base,G6}) * \mathrm{pf}_{G6} + P_{base,G6}}{S_{rated,G6}} \tag{4}$$

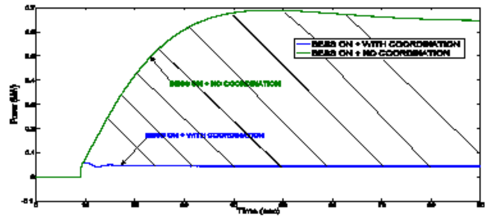
where, $S_{rated,G5}$ and $S_{rated,G6}$ are the rated MVA of the machines.

The secondary load frequency control of MMS, as shown in Fig. 3, measures the system frequency and changes load settings of thermal units via the LFC signal. The MMS calculates the average power that has to be distributed among the thermal units connected to the load frequency controller. The resultant control signal specifies the active power set points to the selected thermal units for power production adjustment based on participation factors, pf_{G5} and pf_{G6} where the sum of the participating factors are equal to unity.

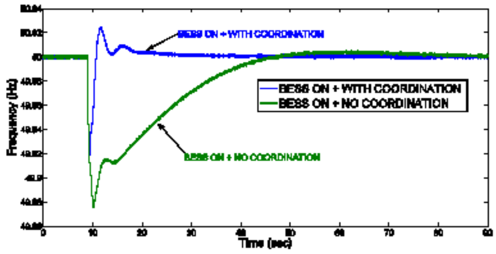
3. Simulation Results

In order to assess the efficacy of the proposed method, a case study has been conducted. In the case study, the system initially has about 21.8 MW load. The centralized MMS control is continuously monitoring the frequency to respond to any disturbance. A 3-phase fault disconnecting the Bornholm power system from the Swedish is applied at ($P_{scr} = 1pu$, $\delta_0 = 0,$ initial power flow of 1.57 MW) at t = 9 sec.

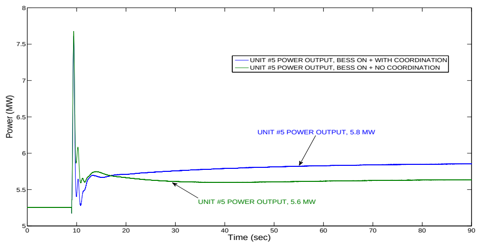
The main focus of the case is to illustrate the role of the BESS and its coordinated control strategy with the MMS. In Fig. 4(a), the power output of the BESS changes from zero to a certain value in order to stabilize the frequency as a fast-acting primary control during the island operation. The power output of the two thermal units also change from initial values to a new power set point calculated by the secondary control, as shown in the Fig. 3 in Section 2. The MMS detects the change of the power output of the BESS and assigns the difference to the thermal units. This secondary regulation can reduce the consumption of the stored energy of the BESS without degrading the control performance. It is observed that a small size BESS (i.e. 0.045 MW) can improve the response of the Bornholm system in the Fig. 4(a, blue curves). The BESS does not need to contribute or compensate the complete power mismatch. Hence, the BESS power requirement is greatly reduced with two other thermal units participating in secondary frequency control. The shaded area in Fig. 4(a) shows the total energy contributions from the two thermal units.



(a)



(b)



(c)

Fig. 4. BESS regulation with and without coordinated control (a) BESS power output; (b) frequency; (c) power output of DG Unit 1

The power BESS injects is shown with legend BESS ON + WITH COORDINATION (blue curves) and the power BESS injects without coordination control is shown with legend BESS ON + NO COORDINATION (green curves), respectively.

In Fig. 4(b), the frequency response is shown with BESS ON + WITH COORDINATION (blue curve) and with BESS ON + NO COORDINATION (green curve). The power injection from DG unit 1 is shown in Fig. 4(e).

4. Conclusion

The BESS is designed to provide frequency support as a fast-acting primary control, and the MMS acts as a supplementary to help maintaining the constant frequency and voltage under islanding operation mode. The case study results with the Bornholm power system that the proposed control strategy can respond very fast and ensure that the frequency remains within limits of the power system. It is observed that using only small amount of the BESS can improve the system response and the secondary regulation can reduce the consumption of the stored energy of BESS without degrading the control performance. Therefore, the results indicate the efficiency of the BESS for real-time applications and its suitability for the real power system case considered.

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